

CHAPTER 610 PAVEMENT ENGINEERING CONSIDERATIONS

Topic 611 - Factors in Selecting Pavement Type

Index 611.1 Pavement Type Selection

The types of pavement generally considered for new construction and rehabilitation in California are rigid, flexible and composite pavements. Rigid pavement should be considered as a potential alternative for all Interstate and other high traffic volume interregional freeways. Flexible pavement should be considered as a potential alternative for all other State highway facilities. Composite pavement, which consists of a flexible layer over a rigid pavement have mostly been used for maintenance and rehabilitation of rigid pavements on State highway facilities.

611.2 Selection Criteria

Because physical conditions and other factors considered in selecting pavement type vary significantly from location to location, the Project Engineer must evaluate each project individually to determine the most appropriate and cost-effective pavement type to be used. The evaluation should be based on good engineering judgment utilizing the best information available during the planning and design phases of the project together with a systematic consideration of the following project specific conditions:

- Pavement design life
- Traffic considerations
- Soils characteristics
- Weather (climate zones)
- Existing pavement type and condition
- Availability of materials
- Recycling
- Maintainability

- Constructibility
- Cost comparisons (initial and life-cycle)

The above factors should be thoroughly investigated when selecting a pavement structure and addressed specifically in all project documents (PSSR, PSR, PR, PS&E, etc). The final decision on pavement type should be the most economical design based on life-cycle cost analysis (see Topic 619.)

The principal factors considered in selecting pavement structures are discussed as follows in Topics 612 through 619.

Topic 612 - Pavement Design Life

612.1 Definition

Pavement design life, also referred to as performance period, is the period of time that a newly constructed or rehabilitated pavement is engineered to perform before reaching its terminal serviceability or a condition that requires pavement rehabilitation, (see Index 603.3(2)). The selected pavement design life varies depending on the characteristics of the highway facility, the objective of the project, and projected traffic volume and loading. The strategy or pavement structure selected for any project should provide the minimum pavement design life that meets or exceeds the objective of the project as described in Topics 612 through 619.

612.2 New Construction and Reconstruction

The minimum pavement design life for new construction and reconstruction projects shall be no less than the values in Table 612.2 or the project design period (see Index 103.2), whichever is greater.

Table 612.2**Pavement Design Life for New Construction and Reconstruction**

Facility	Pavement Design Life (Years)	
	AADT ⁽³⁾ < 150,000 ⁽¹⁾ and AADTT ⁽⁴⁾ < 15,000 ⁽¹⁾	AADT ≥ 150,000 ⁽¹⁾ or AADTT ≥ 15,000 ⁽¹⁾
Mainline Traveled Way	20 or 40 ⁽²⁾	40
Ramp Traveled Way	20 or 40 ⁽²⁾	40
Shoulders:		
≤ 1.5 m wide	Match adjacent traveled way	40
> 1.5 m wide: First 0.6 m	Match adjacent traveled way	40
Remaining width ⁽⁵⁾	20	20
Intersections	20 or 40 ⁽²⁾	40
Roadside Facilities	20	20
Notes:		
(1) Projected mainline AADT and AADTT 20 years after construction		
(2) Use design life with lowest life-cycle cost (See Topic 619)		
(3) Annual Average Daily Traffic (AADT)		
(4) Annual Average Daily Truck Traffic (AADTT)		
(5) If the shoulder is expected to be converted to a traffic lane with the pavement design life, it should be engineered to match some pavement design life as the adjacent traveled way.		

612.3 Widening

Additional consideration is needed when determining the design life for pavement widening. Factors to consider include the remaining service life of the adjacent pavement, planned future projects (including maintenance and rehabilitation), and future corridor plans for any additional lane widening and shoulders. **The pavement design life for widening projects shall either match the remaining pavement service life of the adjacent roadway (but not less than the project design period as defined in Index 103.2), or the pavement design life values in Table 612.2 depending on which has the lowest life-cycle costs.** Life-cycle cost analysis is discussed further in Topic 619.

When widening a roadway, the existing pavement should be rehabilitated and brought up to the same life expectancy as the new widened portion of the roadway.

612.4 Pavement Rehabilitation

The pavement design life for pavement rehabilitation projects shall be a minimum of 5 years to meet FHWA funding criteria.

612.5 Roadway Rehabilitation

The minimum pavement design life for roadway rehabilitation projects shall be 10 or 20 years depending on which design life has the lowest life-cycle costs. For corridors with a current Annual Average Daily Traffic (AADT) of at least 150,000 or Annual Average Daily Truck Traffic (AADTT) of at least 15,000, rehabilitation projects with a 30- or 40-year pavement design life should also be evaluated using the Department LCCA procedure. Life-cycle cost analysis is discussed further in Topic 619.

612.6 Temporary Pavements and Detours

Temporary pavements and detours should be engineered to accommodate the anticipated traffic loading that the pavement will experience during the construction period. The minimum design life for temporary pavements and detours should be no less than the construction period for the project.

This period may range from a few months to several years depending on the type, size and complexity of the project.

612.7 Non-Structural Wearing Courses

As described in Index 602.1(5), a non-structural wearing course is used on some pavements to ensure that the underlying layers will be protected from wear and tear from tire/pavement interaction, the weather, and other environmental factors for the intended design life of the pavement. Because non-structural wearing courses are not considered to contribute to pavement structural capacity, they are not expected to meet the same design life criteria as the structural layers. However, when selecting materials, mix designs and thickness of these courses, appropriate evaluation and sound engineering judgment should be used to optimize performance and minimize the need for maintenance of the wearing course and the underlying structural layers. Based on experience, a properly engineered non-structural wearing course placed on new pavement should perform adequately for 10 or more years, and 5 or more years when placed on existing pavement as a part of rehabilitation or preventive maintenance.

Topic 613 - Traffic Considerations

613.1 Overview

Pavements are engineered to carry the truck traffic loads expected during the pavement design life. Truck traffic, which includes buses, trucks and truck-trailers, is the primary factor affecting pavement design life and its serviceability. Passenger cars and pickups are considered to have negligible effect when determining traffic loads.

Truck traffic information that is required for pavement engineering includes projected volume for each of four categories of truck and bus vehicle types by axle classification (2-, 3-, 4-, and 5-axles or more), axle configurations (single, tandem, tridem, and quad), axle loads, and number of load repetitions. This information is used to estimate anticipated traffic loading and performance of the pavement structure. The

Department currently estimates traffic loading by using established constants for a 10-, 20-, 30-, or 40-year pavement design life to convert truck traffic data into 80 kilo Newton (kN) equivalent single axle loads (ESALs). The total projected ESALs during the pavement design life are in turn converted into a Traffic Index (TI) that is used to determine minimum pavement thickness. Another method for estimating pavement loading known as Axle Load Spectra is currently under development by the Department for future use with the Mechanistic-Empirical design procedure.

613.2 Traffic Volume Projections

- (1) *Traffic Volume and Loading Data.* In order to determine expected traffic loads on a pavement it is first necessary to determine projected traffic volumes during the design life for the facility.

Traffic volume and loading on State highways can come from vehicle counts and classification, weigh-in-motion (WIM) stations, and the Truck Weight Studies data published annually by Headquarters Division of Traffic Operations. Current and projected traffic volume by vehicle classification must be obtained for each project in accordance with the procedures found in this Topic.

Districts typically have established a unit within Traffic Operations or Planning specifically responsible for providing travel forecast information. These units are responsible for developing traffic projections (including truck volumes, equivalent single axle loads, and TIs) used for planning and engineering of State highways in the District. The Project Engineer should coordinate with the forecasting unit in their District early in the project development process to obtain the required traffic projections.

- (2) *Design Year Annual Average Daily Truck Traffic (AADTT):* An expansion factor obtained from the traffic forecasting unit is used to project current AADTT to the design year AADTT for each axle classification (see Table 613.3A). In its simplest form, the expansion factor is a straight-line projection of the current one-way AADTT data. When

using the straight-line projection, the truck traffic data is projected to find the AADTT at the midway of the design life. This represents the average one-way AADTT for each axle classification during the pavement design life.

When other than a straight-line projection of current truck traffic data is used for engineering purposes, the procedure to be followed in developing design year traffic projections will depend on travel forecast information for the region. In such cases, the projections require a coordinated effort of the District's Division of Transportation Planning and Traffic Operations working closely with the Regional Agencies to establish realistic values for truck traffic growth rates based on travel patterns and other socioeconomic factors.

Due to various changes in travel patterns and other socioeconomic factors that may significantly affect design year traffic projections, the TI for facilities with longer service life, such as a 30- or 40-year design life require more effort to determine than for a 10- or 20-year design life. For this reason, the Project Engineer should involve District Transportation Planning and/or Traffic Operations in determining a realistic and appropriate TI for each project early in the project development process. In the absence of 30- or 40-year traffic projection data, 20-year projection data may be extrapolated to 30- and 40-year values by applying the expansion factor.

613.3 Traffic Index Calculation

The Traffic Index (TI) is determined using the following procedures:

- (1) *Determine the Projected Equivalent Single Axle Loads (ESALs).* The information obtained from traffic projections and Truck Weight Studies is used to develop 80 kilo Newton (kN) Equivalent Single Axle Load (ESAL) constants that represent the estimated total accumulated traffic loading for each heavy vehicle (trucks and buses) and each of the four truck types during the pavement design life. Typically, buses are

assumed to be included in the truck counts due to their relatively low number in comparison to trucks. However, for facilities with high percentage of buses such as high-occupancy vehicle (HOV) lanes and exclusive bus lanes, projected bus volumes need to be included in the projection used to determine ESALs. The ESAL constants are used as multipliers of the projected AADTT for each truck type to determine the total cumulative ESALs and in turn the Traffic Index (TI) during the design life for the pavement (see Index 613.3(3)). The ESALs and the resulting TI are the same magnitude for both flexible, rigid, and composite pavement alternatives. The current 10-, 20-, 30-, and 40-year ESAL Constants are shown in Table 613.3A.

- (2) *Lane Distribution Factors.* Truck/bus traffic on multilane highways normally varies by lane with the lightest volumes generally in the median lanes and heaviest volumes in the outside lanes. Buses are also typically found in HOV lanes. For this reason, the distribution of truck/bus traffic by lanes must be considered in the engineering for all multilane facilities to ensure that traffic loads are appropriately distributed. Because of the uncertainties and the variability of lane distribution of trucks on multilane freeways and expressways, statewide lane distribution factors have been established for pavement engineering of highway facilities in California. These lane distribution factors are shown in Table 613.3B.
- (3) *Traffic Index (TI).* The Traffic Index (TI) is a measure of the number of ESALs expected in the traffic lane over the pavement design life of the facility. The TI does not vary linearly with the ESALs but rather according to the following exponential formula and the values presented in Table 613.3C. The TI is determined to the nearest 0.5.

$$TI = 9.0 \times \left(\frac{(ESAL \times LDF)}{10^6} \right)^{0.119}$$

Where:

TI = Traffic Index

ESAL = Total number of cumulative 80 kN Equivalent Single Axle Loads

LDF = Lane Distribution Factor (see Table 613.3B)

Index 613.4 contains additional requirements and considerations for determining projected traffic loads.

Table 613.3A
ESAL Constants

Vehicle Type (By Axle Classification)	10-Year Constants	20-Year Constants	30-Year Constants	40-Year Constants
2-axle trucks or buses	690	1380	2070	2760
3-axle trucks or buses	1840	3680	5520	7360
4-axle trucks	2940	5880	8820	11760
5 or more-axle trucks	6890	13780	20670	27560

Table 613.3B
Lane Distribution Factors for Multilane Highways

Number of Mixed Flow Lanes in One Direction	Factors to be Applied to Projected Annual Average Daily Truck Traffic (AADTT)			
	Mixed Flow Lanes (see Notes 1, 2, 3 & 4)			
	Lane 1	Lane 2	Lane 3	Lane 4
One	1.0	-	-	-
Two	1.0	1.0	-	-
Three	0.2	0.8	0.8	-
Four	0.2	0.2	0.8	0.8

NOTES:

1. Lane 1 is next to the centerline or median.
2. For more than four lanes in one direction, use a factor of 0.8 for the outer two lanes plus any auxiliary/collector lanes, use a factor of 0.2 for other mixed flow through lanes.
3. For HOV lanes, use a factor of 0.2; however, the TI should be no less than 10 for a 20-year, or 11 for a 40-year pavement design life.
4. Lanes devoted exclusively to buses and/or trucks use a factor of 1.0 based on projected AADTT of mixed-flow lanes for auxiliary and truck lanes, and a separate AADTT based on expected bus traffic for exclusive bus lanes.

Table 613.3C
Conversion of ESAL to Traffic Index

ESAL ⁽¹⁾	TI ⁽²⁾	ESAL ⁽¹⁾	TI ⁽²⁾
4710		6 600 000	
	5.0		11.5
10 900		9 490 000	
	5.5		12.0
23 500		13 500 000	
	6.0		12.5
47 300		18 900 000	
	6.5		13.0
89 800		26 100 000	
	7.0		13.5
164 000		35 600 000	
	7.5		14.0
288 000		48 100 000	
	8.0		14.5
487 000		64 300 000	
	8.5		15.0
798 000		84 700 000	
	9.0		15.5
1 270 000		112 000 000	
	9.5		16.0
1 980 000		144 000 000	
	10.0		16.5
3 020 000		186 000 000	
	10.5		17.0
4 500 000		238 000 000	
	11.0		17.5 ⁽³⁾
6 600 000		303 000 000	

Notes:

- (1) For ESALs less than 5000 or greater than 300 million, use the TI equation to calculate design TI, see Index 613.3(3).
- (2) The determination of the TI closer than 0.5 is not justified. No interpolations should be made.
- (3) For TI's greater than 17.5, use the TI equation, see Index 613.3(3).

613.4 Axle Load Spectra

(1) *Development of Axle Load Spectra.* Axle load spectra is an alternative method of measuring heavy vehicle loads that is currently under development for the future mechanistic-empirical design method. Axle load spectra is a representation of normalized axle load distribution developed from weigh-in-motion (WIM) data for each axle type (single, tandem, tridem, and quad) and truck class (FHWA vehicle classes 4 through 13). Axle load spectra do not involve conversion of projected traffic loads into equivalent single axle loads (ESALs), instead traffic load applications for each truck class and axle type are directly characterized by the number of axles within each axle load range.

In order to accurately predict traffic load related damage on a pavement structure, it is important to develop both spatial and temporal axle load spectra for different truck loadings and pavements. The following data is needed to develop axle load spectra:

- Truck class (FHWA class 4 for buses through class 13 for 7+ axle multi-trailer combinations)
- Axle type (single, tandem, tridem, and quad)
- Axle load range for each axle type and truck class (3 to 102 kips)
- The number of axle load applications within each axle load range by axle type and truck class
- The percentage of the total number of axle applications within each axle load range with respect to each axle type, truck class, and year of data. These are the normalized values of axle load applications for each axle type and truck class

The aforementioned data are obtained from traffic volume counts and WIM data for vehicle classification, and axle type and weight. Traffic counts and WIM stations should be deployed widely to ensure that

projected volume estimates for each vehicle class and axle type are in line with the actual volumes and growth rates.

(2) *Use of Axle Load Spectra in Pavement Engineering:* Pavement engineering calculations using axle load spectra are generally more complex than those using ESALs or traffic index (TI) because loading cannot be reduced to one equivalent number. However, the load spectra approach of quantifying traffic loads offers a more practical and realistic representation of traffic loading than using TI or ESALs. Due to its better performance modeling, axle load spectra will be used in the Mechanistic-Empirical (M-E) design method currently under development to evaluate traffic loading over the design life for new and rehabilitated pavements. This information will be used to validate original pavement design loading assumptions, and to continuously monitor pavement performance given the loading spectrum. Axle load spectral data will also be used to facilitate effective and pro-active deployment of maintenance efforts and in the development of appropriate strategies to mitigate sudden and unexpected pavement deterioration due to increased volumes or loading patterns.

In this edition of the Highway Design Manual, axle load spectra are not used to engineer pavements.

613.5 Specific Traffic Loading Considerations

(1) *Traveled Way*

(a) *Mainline Lanes.* Because each lane for a multilane highway with 3 or more lanes in each direction may have a different load distribution factor (see Table 613.3B), multiple TIs may be generated for the mainline lanes which can result in different pavement thickness for each lane. Such a design with different thickness for each lane would create complications for constructing the pavement. Therefore, the decision to use

a single or multiple TI's for the pavement engineering of mainline lanes for a multilane highway with 3 or more lanes in each direction should be based on a thorough consideration of constructibility issues discussed in Index 618.2 together with sound engineering judgment. If one TI is used, it should be the one that produces the most conservative pavement structure.

- (b) Freeway Lanes. TI for new freeway lanes, including widening, auxiliary lanes, and high-occupancy vehicle (HOV) lanes, should be the greater of either the calculated value, 10.0 for a 20-year pavement design life, or 11.0 for a 40-year pavement design life. For pavement rehabilitation and capital preventive maintenance projects, use the calculated TI.

(c) Ramps and Connectors:

1. Connectors. AADTT and TI's for freeway-to-freeway connectors should be determined the same way as for mainline traffic.
2. Ramps to Weigh Stations. Pavement structure for ramps to weigh stations should be engineered using the mainline ESALs and the load distribution factor of 1.0 for exclusive truck lanes as noted in Table 613.3B.
3. Other Ramps. Estimating future truck traffic on ramps is more difficult than on through traffic lanes. It is typically more difficult to accurately forecast ramp AADTT because of a much greater impact of commercial and industrial development on ramp truck traffic than it is on mainline truck traffic.

If reliable truck traffic forecasts are not available, ramps should be engineered using the 10-, 20-, and 40-year TI values given in Table 613.5A for light, medium, and heavy truck traffic ramp classifications. Design

life TI should be the greater of the calculated TI.

The three ramp classifications are defined as follows:

- Light Traffic Ramps - Ramps serving undeveloped or residential areas with light to no truck traffic predicted during the pavement design life.
- Medium Traffic Ramps - Ramps in metropolitan areas, business districts, or where increased truck traffic is likely to develop because of anticipated commercial development within the pavement design life
- Heavy Traffic Ramps - Ramps that will or currently serve industrial areas, truck terminals, truck stops, and/or maritime shipping facilities.

The final decision on ramp truck traffic classification rests with the District.

Table 613.5A
Traffic Index (TI) Values for
Ramps and Connectors

Ramp Truck Traffic Classification	Minimum Traffic Index (TI)		
	10-Yr Design Life ⁽¹⁾	20-Yr Design Life	40-Yr Design Life ⁽¹⁾
Light	8.0	8.0	9.0
Medium	9.0	10.0	11.0
Heavy	11.0	12.0	14.0

Note:

- (1) Based on straight line extrapolation of 20-year ESALs.

(2) Shoulders

- (a) New Construction and Reconstruction. Because shoulders do not typically carry repeated traffic loads like traffic lanes, the pavement structure for the shoulder is engineered based on the traffic loads of the adjacent traffic lane. Preferably, all new or reconstructed shoulders should match the pavement structure of the adjacent traffic lane, except when the thickness of the flexible surface course can vary to account for the difference in cross slope between the traveled way and the shoulder. This strategy has been the most effective over time in optimizing the performance of the shoulders and minimizing maintenance and repair. Besides improved performance, new or reconstructed shoulders that match the pavement structure of the adjacent traffic lane have the following additional benefits:

- Simplify the contractor's operation which leads to reduced working days, fewer material needs, and lower unit prices.
- Provide versatility in using the shoulders as temporary detours for construction or maintenance activities in the future.
- Make it easier and more cost-effective to convert into a traffic lane as part of a future widening.

In some cases, it may not be practical to match the pavement structure of the adjacent traffic lane. Such situations are determined or agreed to by the District on a case-by-case basis provided the minimum requirements stated in this manual are met.

At a minimum, new or reconstructed shoulders shall be engineered using the same TI as the adjacent traffic lane when any of the following conditions apply:

- **The shoulder width is 1.5 meters or less.**

- **Where there are sustained (greater than 1.6 km in length) grades of over 4% without a truck climbing lane.**
- **The shoulders are adjacent to exclusive truck or bus only lanes, or weigh station ramps.**

For all other cases, the minimum TI for the shoulder shall match the TI of the adjacent traffic lane for the first 0.6 m of the shoulder width measured from edge of traveled way. For the remaining width of the shoulder, the TI shall be no less than 2% of the projected ESALs of the adjacent traffic lane or a TI of 5, whichever is greater.

Note that although using a thinner shoulder pavement structure than the traveled way requires less material and may appear to reduce construction costs, the added costs of time and labor to the Contractor to build the "steps" between the traveled way and shoulder can offset the savings from reduced materials.

- (b) Future Conversion to Lane. One new facilities, if the future conversion of the shoulder to a traffic lane is within the pavement design life, the shoulder pavement structure should be equal to that of the adjacent traveled way.

If a decision has been made to convert an existing shoulder to a portion of a traffic lane, a deflection study must be performed to determine the structural adequacy of the in place shoulder pavement structure. The condition of the existing shoulder must also be evaluated for undulating grade, rolled-up hot mix asphalt and the rigid pavement joint, surface cracking, raveling, brittleness, oxidation, etc.

The converted facility must provide a roadway that is structurally adequate for the proposed pavement design life. This is necessary to eliminate or minimize the likelihood of excessive maintenance or rehabilitation being required in a

relatively short time because of inadequate structural strength and deterioration of the existing hot mix asphalt.

- (c) Medians. When a median is 4.2 meters wide or less, the median pavement structure should be equivalent to the adjacent lanes. See Index 305.5 for further paved median guidance.
 - (d) Maintenance and Rehabilitation. Traffic Index is not a consideration in a shoulder maintenance or rehabilitation strategy unless the shoulder will be used to temporarily detour traffic or is expected to carry traffic after construction. In such situations, the existing shoulder pavement structure should be checked for structural adequacy. If the shoulder is not structurally adequate, it should be removed and replaced using the procedures and standards described in Index 613.5(2)(a) for new construction and reconstruction. Regardless of whether or not TI is considered, shoulder maintenance or rehabilitation repairs in the existing shoulder are often necessary and should be done to assure that the shoulder pavement will meet the performance requirements.
- (3) *Intersections.* Future AADTT and TI's for intersections should be determined the same way as for mainline traffic, but with special attention to truck and bus traffic behavior to determine the loading patterns and select the most appropriate materials. The limits for engineering pavement at an intersection should include intersection approaches and departures, to the greater of the following distances:
- For signalized intersections, the limits of the approach should extend past the furthest set of signal loop detectors where trucks do the majority of their braking; or
 - For stop controlled intersections the limits for the approach should be long enough to cover the distance trucks will

be braking and stopping either at the stop bar or behind other trucks and vehicles; or

- 30 meters.

The limits for the intersection departures should match the limits of the approach in the opposing lane to address rutting caused by truck acceleration.

For further assistance on this subject, contact either your District Materials Engineer, or Headquarters Division of Design – Office of Pavement Design.

- (4) *Roadside Facilities.* The pavement for safety roadside rest areas, including parking lots, should meet or exceed the TI requirements found in Table 613.5B for a 20-year pavement design life for new/reconstructed or rehabilitated pavements.

Table 613.5B
Minimum TI's for Safety Roadside Rest Areas

Facility Usage	Minimum TI (20-Year)
Truck Ramps & Roads	8.0 ⁽¹⁾
Truck Parking Areas	6.0 ⁽¹⁾
Auto Roads	5.5
Auto Parking Areas	5.0

Note:

- (1) For safety roadside rest areas next to all Interstates and those State Routes with AADTT greater than 15000 use Table 613.5A medium truck traffic for truck ramps, truck roads, and a minimum TI of 9.0 for truck parking areas.

Topic 614 - Soil Characteristics

614.1 Engineering Considerations

California is a geologically active state with a wide variety of soil types throughout. Thorough understanding of the native soils in a project area is essential to properly engineer or update a highway facility.

Subgrade is the natural soil or rock material underlying the pavement structure. Unlike concrete and steel whose characteristics are fairly uniform, the engineering properties of subgrade soils may vary widely over the length of a project.

Pavements are engineered to distribute stresses imposed by traffic to the subgrade. For this reason, subgrade condition is a principal factor in selecting the pavement structure. Before a pavement is engineered, the structural quality of the subgrade soils must be evaluated to ensure that it has adequate strength to carry the predicted traffic loads during the design life of the pavement. The pavement must also be engineered to limit the expansion and loss of density of the subgrade soil.

614.2 Unified Soil Classification System (USCS)

The USCS classifies soils according to their grain size distribution and plasticity. Therefore, only a sieve analysis and Atterberg limits (liquid limit, plastic limit and plasticity index) are necessary to classify a soil in this system. Based on grain size distribution, soils are classified as either (1) coarse grained (more than 50% retained on the 0.075mm – No. 200 sieve), or (2) fine grained (50% or more passes the 0.075 mm – No. 200 sieve). Coarse grained soils are further classified as gravels (50% or more of coarse fraction retained on the 4.75 mm – No. 4 sieve) or sands (50% or more of coarse fraction passes the 4.75 mm – No. 4 sieve); while fine grained soils are classified as inorganic or organic silts and clays and by their liquid limit (equal to or less than 50%, or greater than 50%). The USCS also includes peat and other highly organic soils, which are compressible and not recommended for

roadway construction. They should be removed wherever possible prior to placing the pavement structure.

The SUCS classifications based on ASTM D2487 are summarized in Table 614.2.

614.3 California R-Value

The California R-value is the measure of resistance to deformation of the soils under saturated conditions and wheel loading. It is used to determine the bearing value of the subgrade. Determination of R-value for subgrade is provided under California Test Method (CTM) 301. Typical R-values used by the Department range from five for very soft material to 80 for treated base material.

The California R-value is determined based on the following separate measurements under CTM 301:

- The exudation pressure test determines the thickness of cover or pavement structure required to prevent plastic deformation of the soil under imposed wheel loads.
- The expansion pressure test determines the pavement thickness or weight of cover required to withstand the expansion pressure of the soil.

Table 614.2
Unified Soil Classification System (from ASTM D2487)

Major Classification Group	Sub-Groups		Classification Symbol	Description
Coarse Grained Soils More than 50% retained on the 0.075 mm (No. 200) sieve	Gravels 50% or more of coarse fraction retained on the 4.75 mm (No. 4) sieve	Clean Gravels	GW	Well-graded gravels and gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels and gravel-sand mixtures, little or no fines
		Gravels with Fines	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	Sands 50% or more of coarse fraction passes the 4.75 mm (No. 4) sieve	Clean Sands	SW	Well-graded sands and gravelly sands, little or no fines
			SP	Poorly graded sands and gravelly sands, little or no fines
		Sands with Fines	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
Fine Grained Soils More than 50% passes the 0.075 mm (No. 200) sieve	Silts and Clays Liquid Limit 50% or less		ML	Inorganic silts, very fine sands, rock four, silty or clayey fine sands
			CL	Inorganic clays of low to medium plasticity, gravelly/sandy/silty/lean clays
			OL	Organic silts and organic silty clays of low plasticity
	Silts and Clays Liquid Limit greater than 50%		MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts
			CH	Inorganic clays or high plasticity, fat clays
			OH	Organic clays of medium to high plasticity
Highly Organic Soils			PT	Peat, muck, and other highly organic soils
Prefix: G = Gravel, S = Sand, M = Silt, C = Clay, O = Organic Suffix: W = Well Graded, P = Poorly Graded, M = Silty, L = Clay, LL < 50%, H = Clay, LL > 50%				

Coarse grained subgrade soils may exhibit high California R-values (greater than 50). For this reason, California R-values should be limited to 50 for subgrade soils. Local experience with these soils should govern in assigning R-value on subgrade. Further discussion may be found on the Department pavement website under Technical Guidance.

The California R-value of subgrade within a project may vary substantially but cost and constructability should be considered in specifying one or several California R-value(s) for the project. Engineering judgment should be exercised in selecting appropriate California R-values for the project to assure a reasonably "balanced design" which will avoid excessive costs resulting from over conservatism. The following should be considered when selecting California R-values for a project:

- If the measured California R-values are in a narrow range with some scattered higher values, the lowest California R-value should be selected for the pavement design.
- If there are a few exceptionally low California R-values and they represent a relatively small volume of subgrade or they are concentrated in a small area, it may be more cost effective to remove or treat these materials.
- Where changing geological formations and soil types are encountered along the length of a project, it may be cost-effective to design more than one pavement structure to accommodate major differences in R-values that extend over a considerable length. Care should be exercised to avoid multiple variations in the pavement structure that may result in increased construction costs that exceed potential materials cost savings.

614.4 Expansive soils

With an expansive subgrade (Plasticity Index greater than 12 and California R-Value less than 10), special engineering or construction considerations will be required. Engineering alternatives, which have been used to compensate for expansive soils, are:

- (a) Treating expansive soil with lime or other additives to reduce expansion in the presence of moisture. Lime is often used with highly plastic, fine-grained soils. When mixed and compacted, the plasticity and swelling potential of clay soils are reduced and workability increased, as lime combines with the clay particles. It also increases the California R-value of the subgrade. Soil treated with lime is considered to be lime treated subbase. Lime treated subbase is discussed further in Chapter 660.
- (b) Replacing the expansive material with a non-expansive material to a depth where the seasonal moisture content will remain nearly constant.
- (c) Providing a pavement structure of sufficient thickness to counteract the expansion pressure.
- (d) Utilizing two-stage construction by placing a base or subbase to permit the underlying material to expand and stabilize before placing leveling and surface courses.
- (e) Stabilizing the moisture content by minimizing the access of water through surface and subsurface drainage and the use of a waterproof membrane (i.e., geotextile fabrics or rubberized asphalt membrane).
- (f) Relocating the project alignment to a more favorable soil condition.

Treatments (a), (b), (c), and (d) should be used with caution since undesirable soil expansion has occurred on some projects where these methods were used. Treatment (e) is considered to be the most effective approach if relocation is not feasible such as in the San Joaquin Delta. The District Materials Engineer determines which treatment is practicable.

The California R-value of the subgrade can be raised above 10 by treatment to a minimum depth of 200 mm with an approved stabilizing agent such as lime, cement, asphalt, or fly ash. Native soil samples should be taken, treated, and tested to determine the California R-value for the treated subgrade. The maximum California R-value that

can be attained for treated subgrade regardless of test results is 40. Treating the subgrade does not eliminate or reduce the required aggregate subbase for rigid or composite pavements in the rigid pavement catalog (see Topic 623). With HMA, treated subgrade can be substituted for all or part of the required aggregate subbase layer. Since aggregate subbase has a gravel factor (G_f) of 1.0, the actual thickness and the gravel equivalent (GE) are equal. When the treated subgrade is substituted for aggregate subbase for flexible pavements, the actual thickness is obtained by dividing the GE by the appropriate G_f which is determined based on unconfined compressive strength (UCS).

$$G_f = 0.9 + \frac{UCS}{6.9}$$

Because the treatment of subgrade soil may be less expensive than the base material, the calculated base thickness can be reduced and the treated subgrade thickness increased because of cost considerations. The base thickness is reduced by the corresponding gravel equivalency provided by the lime treated subgrade soil or subbase. The maximum thickness of lime treated subgrade is limited to 600 mm.

Rigid or composite pavement should not be specified in areas with expansive soils unless the pavement has been adequately treated to address soil expansion. Flexible pavement may be specified in areas where expansive soils are present with the understanding that periodic maintenance would be required.

The District Materials Engineer should be contacted to assist with the selection of the most appropriate method to treat expansive soils for individual projects. Final decision as to which treatment to use rests with the District.

614.5 Subgrade Enhancement Fabric (SEF)

The placement of SEF below the pavement will provide subgrade enhancement by bridging soft areas and providing a separation between soft subgrade fines susceptible to pumping and high quality subbase or base materials. As the soil undergoes deformation, properly placed fabric

when stretched will develop tensile stress. Soft areas may require placement of SEF are defined as:

- Poor soils which are classified in the unified soil classification system (USCS) as sandy clay (SC), silty clay (CL), high plastic clay (CH), silt (ML), high plasticity or micaceous silt (MH), organic silt (OL), organic clay (OH), and peat & mulch (PT).
- Low undrained shear strength (equivalent to California R-value <20).
- High water table, and high soil sensitivity.

The SEF when placed with aggregate subbase provides a working platform for access of construction equipment on subgrade with R-values of 5 to 10.

614.6 Other Considerations

(1) *Fill.* It is difficult to predict where the contractor will place the excavated material as fill on a project. Therefore, the pavement design over a fill section should use the minimum California R-value or USCS classification of the material that is to be excavated as part of the project. If there is any excavated material that should not be used, it should be identified in the Materials Report and noted as appropriate in the PS&E.

(2) *Imported Borrow.* Imported Borrow is used in the construction of embankments when insufficient quality material is available. The California R-value of imported borrow or excavated fill material on the project should be the minimum used for design. When imported borrow of desired quality is not economically available or when all of the earthwork consists of borrow, the California R-value specified for the borrow becomes the design R-value. Since no minimum California R-value is required by the Standard Specifications for imported borrow, a minimum must be specified by Special Provision to cover material placed within 1.2 m of the finished grade.

(3) *Compaction.* Compaction is densification of the soil by mechanical means. The Standard Specifications require no less than 95 percent relative compaction be obtained for a minimum depth of 800 mm below finished grade for the width of the traveled way and auxiliary lanes plus 1 m on each side. The 800 mm depth of compaction should not be waived for the traveled way, auxiliary lanes, and ramps on State highways.

These specifications sometimes can be waived by special provision with approval from the District Materials Engineer, when any of the following conditions apply:

- A portion of a local road is being replaced with a stronger pavement structure.
- Partial-depth reconstruction is specified.
- Existing buried utilities would have to be moved.
- Interim widening projects are required on low volume-roads, intersection channelization, or frontage roads.

Locations where the 800 mm compaction depth is waived must be shown on the typical cross sections of the project plan. If soft material below this depth is encountered, it must be removed and replaced with suitable excavated material, imported borrow or subgrade enhancement fabric. Location(s) where the Special Provisions apply should be shown on the typical cross section(s).

Topic 615 - Climate

The effects that climate will have on pavement must be considered as part of pavement engineering. Temperatures will cause pavements to expand and contract creating pressures that can cause pavements to buckle or crack. Binders in flexible pavements will also become softer at higher temperatures and more brittle at colder temperatures. Precipitation can increase the potential for water to infiltrate the base and subbase layers thereby weakening their structural

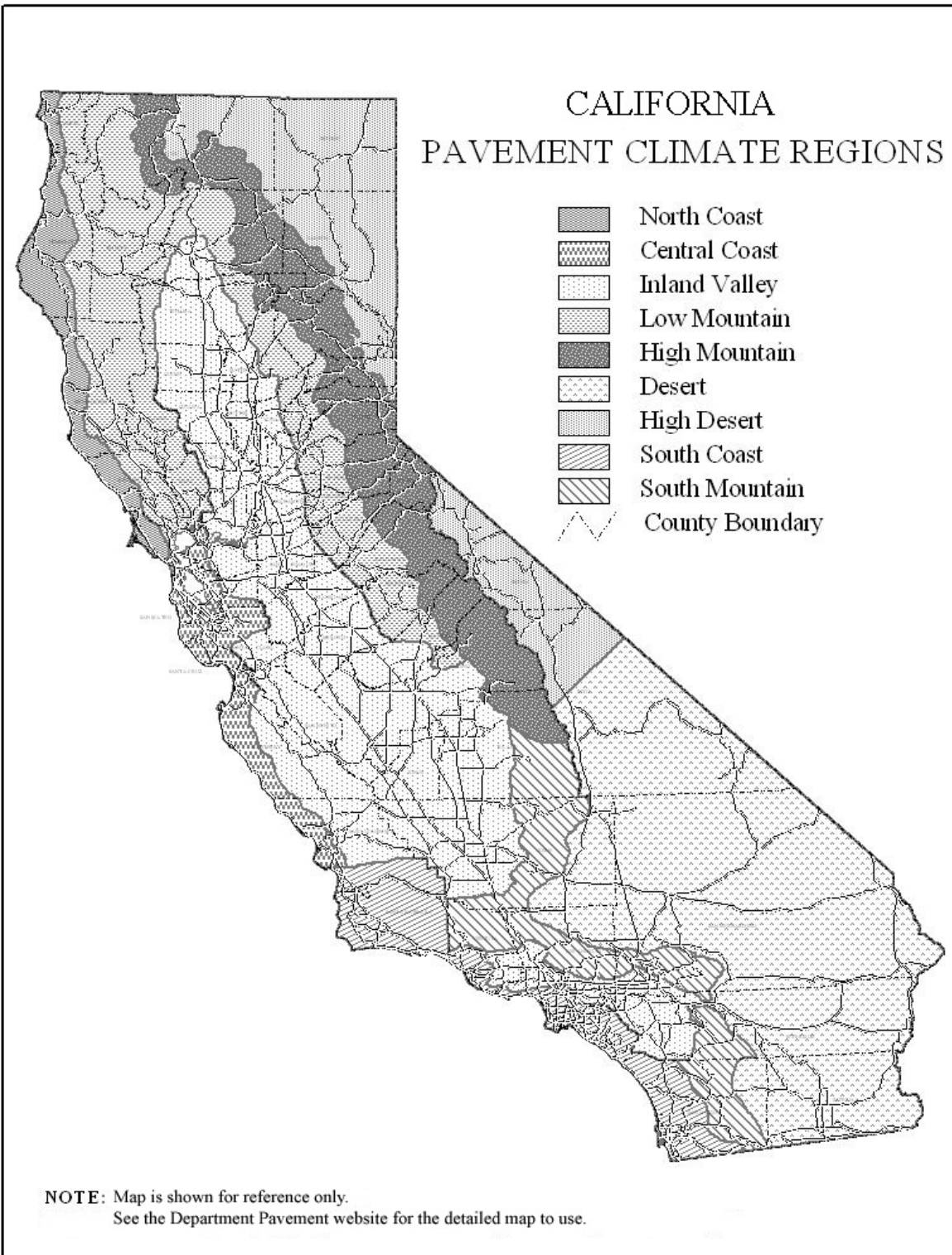
strength and increased susceptibility to erosion. In freeze/thaw environments, the expansion and contraction of water as it freezes plus the use of salts, sands, chains, and snow plows create additional stresses on these pavements. Solar radiation can also cause some pavements to oxidize. To account for these differences, the State has been divided into the following nine climate regions.

- North Coast
- Central Coast
- South Coast
- Low Mountain
- High Mountain
- South Mountain
- Inland Valley
- Desert
- High Desert

Figure 615.1 provides a representation of where these regions are. A more detailed map along with a detailed list of where State routes fall within each climate region can be found on the Department pavement website.

In conjunction with this map, designs, standards, plans, and specifications have been and are being developed to tailor pavement standards and practices to meet each of these climatic conditions. The standards and practices found in this manual, the Standard Plans, Standard Specification, and Special Provisions should be considered as the minimum requirements to meet the needs of each climate region. Districts may also have additional requirements based on their local conditions. Final decision for the need for any requirements that exceed the requirements found in this manual, the Standard Plans, Standard Specifications, and Standard Special Provisions rests with the District.

Figure 615.1
Pavement Climate Regions



Topic 616 - Existing Pavement Type and Condition

The type and condition of pavement on existing adjacent lanes or facilities should be considered when selecting pavement structures or strategies. The selection process and choice made by the engineer is influenced by their experience and knowledge of existing facilities in the immediate area that have given adequate service. Providing continuity of existing pavement type will also ensure consistency in maintenance operations.

In reviewing existing pavement type and condition, the following factors should be considered:

- Type of pavement on existing adjacent lanes or facilities
- Performance of similar pavements in the project area
- Corridor continuity
- Maintaining or changing grade profile
- Existing pavement widening with a similar material
- Existing appurtenant features (median barriers, drainage facilities, curbs and dikes, lateral and overhead clearances, and structures which may limit the new or rehabilitation pavement structure.)

Topic 617 - Materials

617.1 Availability of Materials

The availability of suitable materials such as subbase and base materials, aggregates, binders, and cements for pavements should be considered in the selection of pavement type. The availability of commercially produced mixes and the equipment capabilities of area contractors may also influence the selection of pavement type, particularly on small widening, reconstruction or rehabilitation projects. Materials which are locally available or require less energy to produce and transport to the project site should be used whenever possible.

617.2 Recycling

The Department encourages and seeks opportunities to utilize recycled materials in construction projects whenever such materials meet the minimum engineering standards and are economically viable. Accordingly, consideration should be given on every project to use materials recycled from existing pavements as well as other recycled materials such as tires. Existing pavements can be recycled for use as subbase and base materials, or as a partial substitute for aggregate in flexible surface course for rehabilitation or reconstruction projects. The decision to use recycled materials however should be made on a case-by-case basis based on a thorough evaluation of material properties, performance experience in prior projects, benefit/cost analysis, and engineering judgment. Additional information on use of recycled pavements is available in Index 110.11 and on the Department pavement website.

Candidates for recycling flexible pavement surface courses are those with uniform asphalt content. The existence of heavy crack-sealant, numerous patches, open-graded friction course, and heavy seal coats make the new recycled hot mix asphalt design inconsistent thereby resulting in mix properties that are more difficult to control. To avoid this problem when it occurs and still use the recycle option, for flexible pavement, a minimum of 0.08 ft (25 mm) should be milled off prior to the recycling operation. Light crack sealing (less than 5 % of the pavement) or a uniform single seal coat will not influence the pavement engineering sufficiently to require milling.

The Department has established a minimum mill depth of 45 mm for recycling flexible pavement surface courses. Since existing surface course thickness will have slight variations, the recycling strategy should leave at least the bottom 45 mm of the existing flexible surface course in place. This is to insure the milling machine does not loosen base material and possibly contaminate the recycled material. As mentioned in Index 110.11(2), recycling of existing hot mix asphalt must be considered, in all cases, as an alternative to placing 100% new hot mix asphalt.

Topic 618 - Maintainability and Constructibility

618.1 Maintainability

Maintainability is the ability of a highway facility to be restored in a timely and cost-effective way with minimal traffic exposure to the workers and minimal traffic delays to the traveling public. It is an important factor in the selection of pavement type and pertinent appurtenances. Maintainability issues should be considered throughout the project development process to ensure that maintenance needs are adequately addressed in the engineering and construction of the pavement structure. For example, while a project may be built timely and cost-effectively, it may not necessarily have been engineered with consideration as to how it will be maintained. An item can be shown on the plans such that it is easy to construct but it creates conditions requiring increased worker exposure and increased maintenance effort that is more expensive and labor intensive. Another example is the pavement drainage systems that need frequent replacement and often do not provide access for cleanout.

Besides the minimum considerations for the safety of the public and construction workers found in this manual, the Standard Specifications, and other Department manuals and guidance, greater emphasis should also be placed on the safety of maintenance personnel and long-term maintenance costs over the service life for the proposed project rather than on constructability or initial costs. Minimizing exposure to traffic through appropriate pavement type selection and sound engineering practices should always be a high priority. The District Maintenance Engineer and Maintenance Supervisor responsible for maintaining the project after it is built should be consulted for recommendations on addressing maintainability.

618.2 Constructibility

Construction issues that influence pavement type selection include: size and complexity of the project, stage construction, lane closure requirements, traffic control and safety during

construction, construction windows when the project must be completed, and other constructibility issues that have the potential of generating contract change orders.

The Project Engineer must be cognizant of the issues involved in constructing a pavement, and provide plans and specifications that both meets performance standards and requirements. The construction engineer for the area where the pavement will be built should be consulted regarding constructibility during the project development process. The recommendations given by Construction should be weighed against other recommendations and requirements for the pavement. Constructibility recommendations should be accommodated where practical, provide minimum performance requirements, safety, and maintainability. Some constructibility items that should be addressed in the project include:

- Clearance width of paving machines to barriers and hinge points.
- Access for delivery trucks and construction equipment.
- Ability to safely and efficiently move traffic during construction.
- Time and cost of placing multiple thin lifts of different materials as opposed to thicker lifts of a single material. (For example, sometimes it is more efficient and less costly to place one thick lift of aggregate base rather than two thin lifts of aggregate base and subbase).
- The impact of combined lifts of different materials on long-term performance or maintenance of the pavement. (For example, it may seem to be a good idea to combine layers of portland cement concrete and lean concrete base into a single layer to make it easier to construct, but combining these layers has a negative impact on the pavement performance and will lead to untimely failure).
- Time and cost of using multiple types of hot mix asphalt on a project in an area away from commercial hot mix asphalt sources.

Topic 619 - Life-Cycle Cost Analysis

619.1 Life-Cycle Cost Analysis

Life-cycle cost analysis (LCCA) is a useful tool for comparing the value of alternative pavement structures and strategies. LCCA is an economic analysis that compares initial cost, future cost, and user delay cost of different pavement alternatives. LCCA is an integral part of the decision making process for selecting pavement type and design strategy. It can be used to compare life-cycle cost for:

- Different pavement types (rigid, flexible, composite).
- Different rehabilitation strategies.
- Different pavement design lives. (5 vs. 10, 10 vs. 20, 20 vs. 40, etc).

Note that when doing LCCA, the alternatives being evaluated should have identical improvements. For example, comparing 10-year rehabilitation vs. 20-year rehabilitation or flexible pavement new construction vs. rigid pavement new construction has an identical improvement. Conversely, comparing pavement rehab to new construction, or pavement overlay to pavement widening are not identical improvements.

LCCA can also be useful to determine the value of combining multiple projects into a single project. For example, combining a pavement rehabilitation project with a pavement widening project may reduce overall user delay and construction cost. In such case, LCCA can help determine if combining projects can reduce overall user delay and construction cost for more efficient and cost-effective projects. LCCA could also be used to identify and measure the impacts of separating a project into multiple projects.

LCCA must conform to the procedures and data in the "Life-Cycle Cost Analysis Procedures Manual." LCCA must be completed for any project with pavement cost except for the following:

- Pavement Preservation

- Minor A
- Safety and bridge rehabilitation/replacement with cost less than \$500,000.

The District, can still on a case-by-case basis, decide to perform an LCCA for the excepted projects listed above. For new construction projects, an LCCA analysis comparing rigid/composite and flexible pavement alternatives must be done when the project TI is greater than 10 and both alternatives are constructible. Rubberized asphalt concrete must be considered as an alternative when flexible pavement is being considered and there is no justified reason that rubberized asphalt concrete is not viable for the location. See the Asphalt Rubber Usage Guide for further information. LCCA comparisons must be made between properly engineered, viable pavement structures that would be approved for construction if selected. For analysis purposes, alternatives with life-cycle costs within 10% of each other over the same analysis period are considered to be equivalent when making engineering decisions.